EXPERIMENT 10

HALF-WAVE/FULL-WAVE RECTIFIERS AND FILTER CIRCUITS

Structure

10.1 INTRODUCTION

From your school physics course and in Experiment 9, you know that materials can be broadly classified into conductors, insulators and semiconductors. The resistivity of a conductor is of the order of $10^{-7}\,\Omega\text{m}$ and that of an insulator is of the order of $10^{12} - 10^{24}\,\Omega\text{m}$. The resistivity of a semiconductor lies in between the resistivities of a conductor and an insulator. An intrinsic semiconductor also acts as a near perfect insulator. But with increase in temperature, the conductivity of the semiconductor increases. The change in conductivity with temperature is different for different semiconducting materials.

You have learnt about semiconductors in Experiment 9. You know that examples of commonly used semiconductors are Germanium (Ge) and Silicon (Si). You also know that the conductivity of a semiconductor can be influenced by doping it with dopant elements like boron, phosphorous, arsenic etc. Depending on the nature of the dopant (trivalent or pentavalent) added, they are classified as *p*-type (hole carriers) or *n*-type (electron carriers), respectively. You have obtained *I-V* characteristics of *p-n* junction diode in Experiment 9. Diodes are extensively used in our daily life in electronic equipments/instruments like radio, T.V., amplifiers, musical keyboards, etc. Even the microelectronic chips, which are the core of computers, use diodes.

As you know, we receive alternating current (ac) supply in our houses. However, many gadgets and devices around us such as telephones, computers, radio, T.V. need direct current (dc) supply for their operation. Hence, it is necessary to convert this ac into dc. The conversion of ac voltage into dc voltage is known as **rectification**. You have learnt in Experiment 9 that a *p-n* junction diode works as a rectifier. In all electronic instruments there is a section inside the equipment, known as the **power supply section** which converts ac into dc with the help of rectifiers. The rectified voltage is pulsating and has a small ac component. It is desirable to convert the pulsating dc into constant dc and reduce the ac component of the rectified voltage so that the output is a pure dc voltage. This is accomplished by means of **filters**, which are composed of suitably connected capacitors, inductors and their combinations in different ways.

The *rms* value of ac current is one that will produce the same quantity of heat as that by an equal dc current. The voltage measured using the ac range in a multimeter gives the *rms* value of the ac voltage.

The effectiveness of the filter is given by the **ripple factor** γ. It is defined as the ratio of *rms* value of the ac component of the voltage to the dc voltage (or average value of the voltage). In this way we can identify the purity of the dc output in terms of ripple factor. It is desirable that the ripple factor is as small as possible. The capacitance filter has low ripple at heavy loads, while the inductor filter has low ripple at small loads. Depending on the requirements, suitable filters can be selected. You will also learn about the efficiency.

In the first part of this experiment, you will use *p-n* junction diodes to construct half-wave and full-wave rectifiers and observe the waveforms on the cathode ray oscilloscope (CRO). You will also use capacitors and inductors as filters and observe the output waveforms on the CRO. You will measure the output voltages (both dc and ac) with the help of a multimeter and then calculate the ripple factor of these filters.

In the second part of this experiment, you will observe the effect of L and Pi (π) filters on the output waveform of a full wave rectifier and then calculate the ripple factors in these two filters.

Expected Skills

After doing this experiment, you should be able to

- design and construct half-wave and full-wave rectifier circuits using step-down transformer and diodes;
- study the output waveform and measure the output voltages of half-wave and full-wave rectifiers using a CRO;
- show the effect of the filter (capacitor, inductor, L- and π-filters) on the output voltage of a rectifier and compute ripple factor; and
- distinguish between the outputs of L- and π-filters.

The apparatus required to perform this experiment is listed ahead.

Apparatus required

Centre-tapped transformer (9 V – 0 – 9 V), *p-n* junction diodes – four (IN4007, BY126 or BY127), Electrolytic capacitors (1000 μF, 25 V), Inductors – (150 mH), Resistors – (100Ω – 2kΩ), Connecting wires, bread board, soldering set-up, CRO, Multimeter.

10.2 THEORY OF RECTIFIERS

To understand the rectification action of a *p-n* junction diode, study the circuits shown in Figs. 10.1 and 10.2 and observe the input and output waveforms shown in Fig. 10.1a and c and 10.2a and c. We now describe how the diode works as a rectifier. There are two types of rectifiers: Half-wave rectifier and full-wave rectifier. First we discuss the half-wave rectifier.

The *p-n* junction diode is generally used as a rectifier.

10.2.1 Half-wave Rectifier

As we know, the ac voltage from the mains is sinusoidal (Fig. 10.1a). When we place a diode in a circuit with an ac input voltage, it allows current to flow in only one direction (recall Sec. 9.3.3 of Experiment 9) in the circuit.

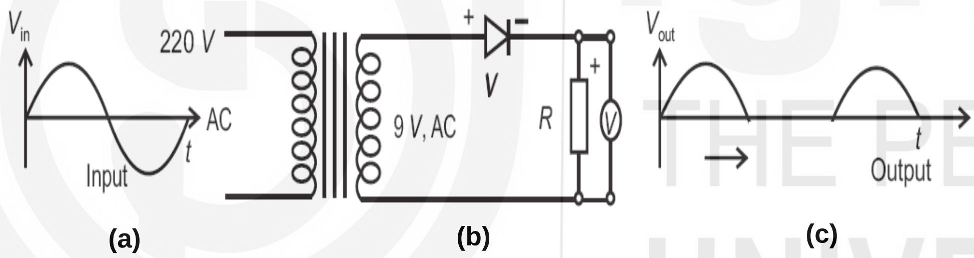


Fig. 10.1: **a) Input ac signal; b) half-wave rectification; c) rectified output signal.**

In the circuit given in Fig. 10.1b, we have used a step-down transformer, a semiconductor diode and load resistance. A sinusoidal 9 V input voltage signal V_{in} from a step down transformer is applied across the diode connected in series with the load resister R_L. During the positive half of the sinusoidal cycle, the diode is forward biased, i.e., anode is positively biased and current flows through the diode. During the negative half of the sinusoidal cycle, the diode is reverse biased and there is no current in the circuit. As a result, in the output signal, the negative half-cycle is eliminated and we obtained a pulsating dc (Fig. 10.1c). Thus, the input signal has been modified (rectified) to the extent that only one-half part of the input is available as the output. The variation of current though the diode results in the variation of voltage drop across R_L as shown in the Fig. 10.1c.

However, a single diode as a half wave rectifier has little use because the output is not dc. This is overcome by using two or four diodes in full wave rectifier. You will learn about full-wave rectifier in the next section.

10.2.2 Full-Wave Rectifier

There are two types of full-wave rectifiers. In one, a centre tapped transformer is used while the other is a bridge rectifier. We discuss them briefly.

A) Full-wave rectifier using centre tapped transformer

In this type of full-wave rectifier, a centre-tapped step down transformer and two diodes are used to achieve full wave rectification (Fig. 10.2b).

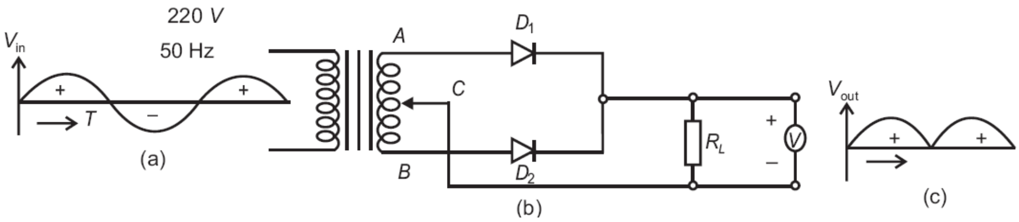


Fig. 10.2: **a) Input ac signal; b) full-wave rectifier; c) rectified output signal.**

At any moment during a cycle of V_{in}, if point A is positive relative to C, point B is negative relative to C. So, the voltage applied to the anode of each diode is equal but opposite in polarity at any given instant.

In one half of the input cycle, when A is positive relative to C, the anode of D_1 is positive with respect to its cathode. Hence D_1 will conduct current but D_2 will not. During the second half of the input cycle, B is positive relative to C. The anode of D_2 is therefore positive with respect to its cathode, and conducts while D_1 does not.

Since the two diodes have a common-cathode load resistor R_L, the output voltage across R_L results from the alternate conduction of D_1 and D_2. So, during the entire input cycle, either D_1 or D_2 conducts current so that the output voltage takes the form shown in Fig. 10.2.

You can, however, see that the output of a full wave rectifier is also pulsating direct current. A centre-tapped transformer is fairly costly. Now, you may ask: how can rectification be achieved without using a centre-tapped transformer? Let us find out.

B) Full wave bridge rectifier

Rectification can be achieved with a normal transformer in a bridge rectifier circuit, which consists of four diodes. Its circuit is shown in Fig. 10.3. You can see that diodes D_1 and D_3 conduct in the positive half cycle, while D_2 and D_4 conduct in negative half cycle.

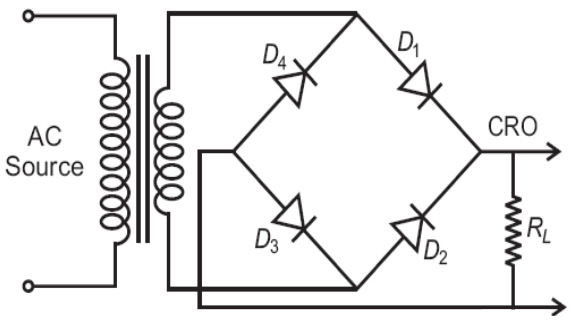


Fig. 10.3: **Bridge rectifier circuit.**

10.3 PROCEDURE TO OBTAIN OUTPUT WAVEFORM USING RECTIFIERS

Now you have understood how half-wave and full-wave rectifiers work, you can do the experiments. In the first experiment, you will design a half-wave rectifier.

10.3.1 Half-wave Rectifier

In this experiment, you will learn how to construct a half-wave rectifier. You will trace the output waveform using a CRO and measure the output voltage. You will need a step-down transformer, *p-n* junction diode, resistor, and bread board or soldering set up (comprising soldering iron, solder and resin) to do this experiment.

Follow the procedure given below to design and construct the half-wave rectifier:

1. Check the continuity of the primary and secondary winding of the step-down transformer using a multimeter.
2. Identify the anode and cathode terminals of the diode as you have learnt in Sec. 9.3.3 of Experiment 9. If the markings on the diode are not clear, find the polarity using the multimeter. (Recall that you can identify the polarity of the diode by either forward biasing or reverse biasing it.)
3. Make the circuit connections for the half-wave rectifier as shown in Fig. 10.1. Apply input voltage (220 V ac).
4. Measure the ac input voltage, and dc output voltage across the load resistance R_L (= 500 Ω) using ac and dc voltmeters, respectively or multimeter in the appropriate mode. Record the readings in Observation Table 10.1.
5. Calculate the ripple factor $(\gamma = V_{ac} / V_{dc})$ and efficiency $\eta = \dfrac{V_{dc}^2}{V_{ac}^2 + V_{dc}^2}$

   and record them in Observation Table 10.1.

Observation Table 10.1: Half-wave rectifier

Sl. No.	R_L(Ω)	V_{ac} (V)	V_{dc} (V)	Ripple factor (γ)	Efficiency (η)
1.	500				
2.	1000				
3.	1500				
4.	2000				
5.	⋮				

6. Repeat Steps 4 and 5 for at least four values of R_L as given in Table 10.1

7. Connect the output voltage across R_L to the Y input of the CRO. Adjust the appropriate time base and V/div to get a stable wave pattern on the screen.

8. Trace the output on a tracing paper, and paste this report in your practical notebook. Compare the figure with the expected figure shown in Fig. 10.1c.

10.3.2 Full-Wave Rectifier

In this part of the experiment, you will learn how to construct a full-wave rectifier. You will also observe the output waveform using a CRO and measure the output voltage using two methods.

A. Using a centre-tapped transformer and two diodes.

Take a centre-tapped step down transformer (9V – 0 – 9V) and follow the steps described below.

1. To begin with, follow Steps 1 and 2 as described in Sec. 10.3.1.

2. Make the circuit connections for the full-wave rectifier as shown in Fig. 10.2. You can use breadboard for connecting the circuit components.

3. Measure the ac input voltage and the rectified (dc) voltage across the load resistance R_L using a voltmeter or multimeter and record them in the Observation Table 10.2 given below.

Observation Table 10.2: Full-wave rectifier

Sl. No.	$R_L(\Omega)$	V_{ac} (V)	V_{dc} (V)	Ripple factor (γ)	Efficiency (η)
1.					
2.					
3.					
4.					
5.					
6.					
⋮					

4. Repeat Steps 1 to 3 for at least four more values of R_L.

5. Connect the output voltage across R_L to the Y input of CRO.

6. Trace the output waveform on a tracing paper, and paste it in your practical notebook. Compare the figure with the expected figure shown in Fig. 10.2c.

B. Using bridge rectifier

You have learnt in Sec. 10.2.3 that a bridge rectifier consists of a normal transformer instead of a centre-tapped transformer. In the bridge rectifier, there are four diodes as shown in Fig. 10.3.

1. Make the circuit connections for the full-wave rectifier using the bridge rectifier shown in Fig. 10.3. You can use a breadboard for connecting the circuit.
2. Measure the ac input voltage and dc output voltage across the load resistance R_L using a voltmeter or multimeter. Record your readings in Table 10.3. Note that diodes D_1 and D_3 conduct in the positive half cycle while diodes D_2 and D_4 conduct in the negative half cycle.
3. Now vary the value of R_L and record the output voltage for each R_L.
4. Connect the output voltage across R_L to the Y-input of CRO.
5. Trace the output waveform and observe whether it is different from the output obtained using the centre-tapped transformer.

Observation Table 10.3: Bridge rectifier

Sl. No.	$R_L(\Omega)$	V_{ac} (V)	V_{dc} (V)	Ripple factor (γ)	Efficiency (η)
1.					
2.					
3.					
4.					
5.					
6.					
⋮					

You will note that the output voltage from rectifiers exhibits fluctuations and cannot be put to any practical use. To minimise fluctuations, we use filters. In the next part of the experiment, you will learn about different types of filters.

10.4 THEORY OF FILTER CIRCUITS

In this experiment, you will use four types of filter circuits: (a) capacitor input filter, (b) inductor filter, and (c) L-section and π-section filters. We now briefly describe the underlying theory for each kind of filter.

10.4.1 Capacitor Input Filter

The capacitor input filter is shown in Fig. 10.4.

Here the high value capacitor is connected across the output voltage.

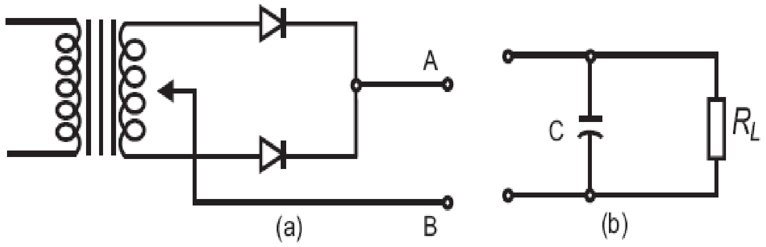


Fig. 10.4: **Capacitor input filter.**

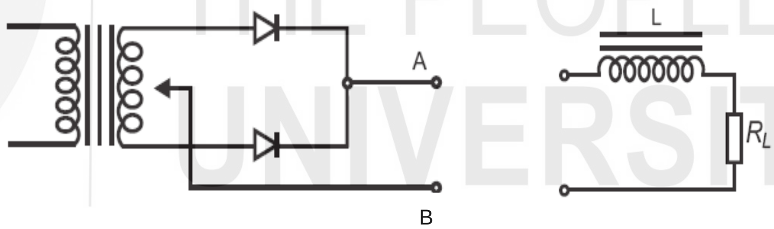
In Sec. 10.3.2, you have learnt about full-wave rectifier (shown in Fig. 10.4a). The output of the rectifier contains both ac and dc components. When the capacitor is connected across the output terminal, *A* and *B*, (Fig. 10.4b) ac components are by-passed while the dc component is blocked and they develop a voltage across the capacitor. Now the capacitor is discharged through the load resistance R_L, which is of high value. So it delivers continuous dc across the load resistor.

Now in the next section, you will study about another filter known as inductor filter.

10.4.2 Inductor Filters

Connect between *A* and *B* (in Fig. 10.4a) an inductor *L* and the load resistor R_L as shown in Fig. 10.5b.

While a capacitor filters out AC component, an inductor allows maintenance of DC level. For details you should refresh your knowledge by reading your 12th standard physics book.



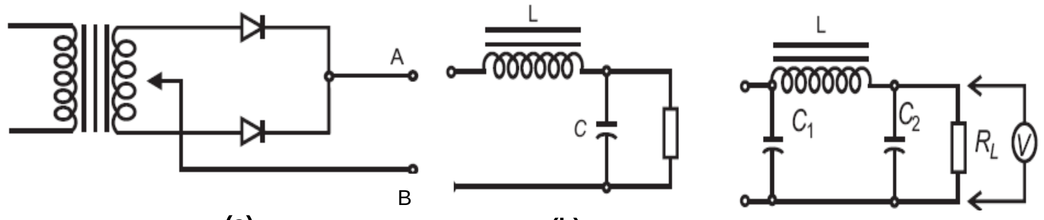
(a) **(b)**

Fig. 10.5: **Inductor filters.**

In your school physics, you must have studied about inductive reactance (denoted by X_L). The impedance of an inductor is $2\pi fL$, where *f* represents frequency and *L*, its inductance. If both ac and dc are flowing through an inductor, it has a high impedance for ac but not for dc So we will find a constant dc voltage across the load. In this way it will remove ripples (i.e., ac components) and convert pulsating dc into constant dc.

10.4.3 L- and π-section Filters

The ripple factor can be further reduced by a combination of inductor and capacitor. The combination of *L* and *C* as shown in Fig. 10.6b is known as **L-section** filter and the combination of *L* and *C* shown in Fig. 10.6c is known as a **π-section** *LC* filter.



(a) (b) (c)

Fig. 10.6: **L and π-section filters.**

Now that you have learnt about various filter circuits, you can connect them and do some more experiments.

10.5 PROCEDURE TO OBTAIN OUTPUT WAVEFORM USING FILTERS

There are three parts in this experiment. You will be connecting all filter circuits to obtain the output waveform.

10.5.1 Capacitor Filters

First you will use the capacitor filter to obtain the output waveform. You will calculate the ripple factor and record the output waveform with and without filters.

1. Connect the circuit of a full wave rectifier as shown in Fig. 10.4a.

2. Choose load resistance R_L = 1000 Ω.

3. Connect a capacitor of value (1 μF, 25 V) (electrolytic capacitor) in parallel with load resistance R_L as shown in Fig. 10.4b and connect it to the terminals *A* and *B* as shown in Fig. 10.4a. The complete circuit is given in Fig. 10.7.

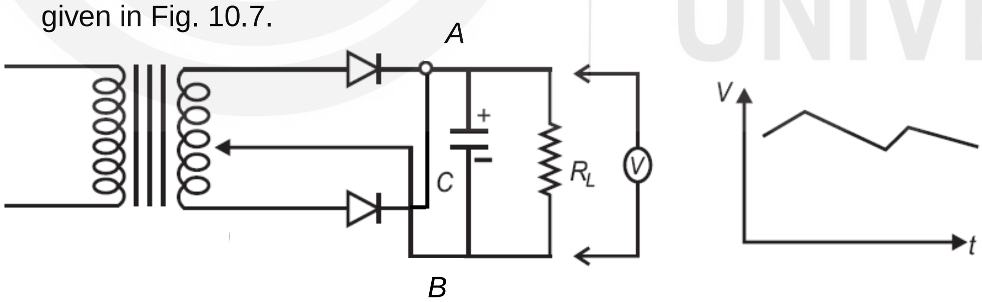


Fig. 10.7: **Circuit diagram of a full-wave rectifier with capacitor filter.**

Note that the circuit has only a simple capacitor filter.

4. Measure the two output voltages (dc and ac voltage) using a multimeter across R_L and record the readings in the Observation Table 10.4 given below. Complete the table by calculating the ripple factor. Trace the output waveform with and without the capacitor, using the CRO. Repeat the experiment for different values of R_L. Calculate the ripple factor for each load and tabulate all values.

5. Choose four values of capacitance: 1 μF, 10 μF, 47 μF and 100 μF for the same R_L and repeat step 4.

Observation Table 10.4: Capacitor filter

Load resistance (R_L) = ...Ω

S. No.	C (μF)	Output (dc) Voltage (V)	Output (ac) Voltage (V)	Ripple factor $\gamma = \frac{V_{ac}}{V_{dc}}$
1	1			
2	10			
3	47			
4	100			

6. Repeat Step 4 and Observation Table 10.4 for other values of R_L.

7. Record the waveforms of the output voltage with and without capacitor for all values of R_L and C (trace each output waveform from the CRO screen and paste it in your practical notebook).

8. Draw a graph by plotting $1/C$ (on the x-axis) and γ, the ripple factor (on the y-axis). Determine the slope of the graph.

***SAQ 1* – Capacitor filters**

What are your observations when you compare the waveform of the output with and without the capacitor? Note them in your practical notebook.

10.5.2 Inductor Filters

Now you will take measurements using the inductor filter and calculate the ripple factor.

1. Follow steps 1 and 2 given in Section 10.5.1.

2. With the circuit given in Fig. 10.5a, between A and B connect the circuit given in Fig. 10.5b. Here the inductor is connected in series. The complete circuit shown below in Fig. 10.8 is called **inductor filter**.

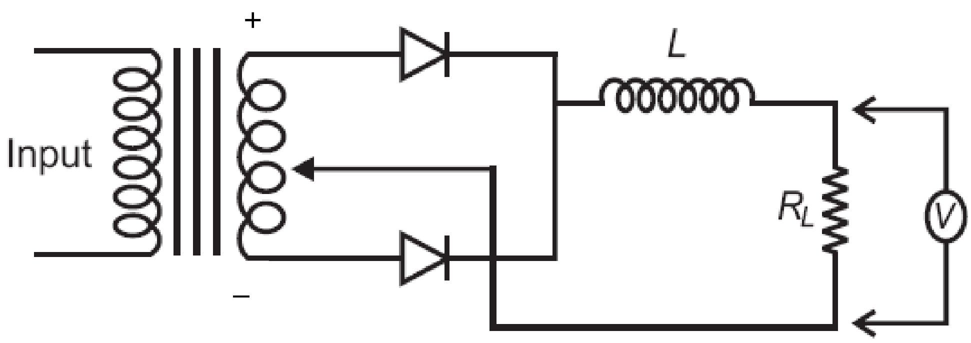


Fig. 10.8: **Circuit diagram of inductor filter.**

3. Connect the primary of the transformer to the mains and measure the output voltage across R_L (both ac and dc). Repeat the steps for different R_L values and tabulate your data in the Observation Table 10.5.

Observation Table 10.5: Inductor filter

S.No.	Load resistance R_L (Ω)	Output (ac) Voltage (V)	Output (dc) Voltage (V)	Ripple factor $\gamma = \frac{V_{ac}}{V_{dc}}$
	1000 Ω			

So far you have learnt about capacitor filter and inductor filter. in the next section, you will perform experiments with L- and π-section filters.

10.5.3 L- and π-section Filters

In this part of the experiment you will build a filter with both inductor and capacitor. Depending on the shape of the circuit formed by their arrangement, they are called *L*- or π-section filters. In this part of the experiment, you will compare the ripple factors for these two filters.

In the previous part of the experiment you have used an inductor as a filter. You will now use a combination of an inductor and a capacitor in the *L*-section filter.

L-section filter

Follow the procedure outlined below.

1. Modify the circuit of inductor filter by connecting a capacitor in parallel to the load resistance, R_L, as shown in Fig. 10.9. This combination of inductor and capacitor is known as an **L-section filter**.
2. Now measure V_{dc} and V_{ac} across the load as you have done earlier in this experiment.
3. Record your readings in Observation Table 10.6.
4. Repeat the experiment for different values of load resistances and record your readings in Observation Table 10.6.
5. Calculate the ripple factor for each load (say, 4kΩ, 6kΩ and 10kΩ).

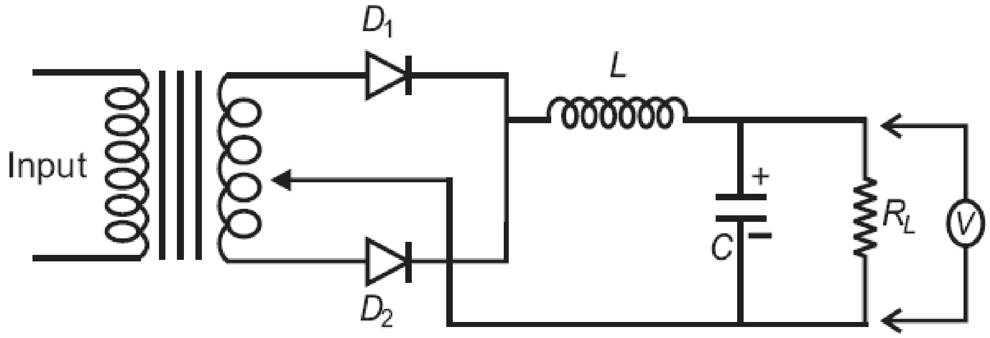


Fig. 10.9: **Circuit diagram for L-section filter.**

Observation Table 10.6: L-section filter

S.No.	Load resistance R_L (Ω)	Output (dc) Voltage V_{dc} (volts)	Output (ac) Voltage V_{ac} (volts)	Ripple factor $\gamma = \frac{V_{ac}}{V_{dc}}$

6. Now connect the output of load resistance R_L to the Y plate of the cathode ray oscilloscope (CRO) and observe the output waveform. Trace the waveform for each value of R_L on a tracing paper and paste all of them in your practical notebook.

SAQ 2 – *C*, *L* and L-section filters

Compare the output waveforms of *C*, *L* and L-section filters. Write your conclusion in your practical notebook.

SAQ 3 – Ripple factor

What is the difference in the ripple factors of *L*, *C* and L-section filters?

π-filter

For the π-filter, follow the steps given below.

1. Connect one more capacitor before the inductor, in parallel to the previous capacitor as shown in Fig. 10.10. (You can take C_1 = 10 μF, C_2 = 47 μF and R_L = 500 Ω). Such a combination is known as a Pi-section filter.

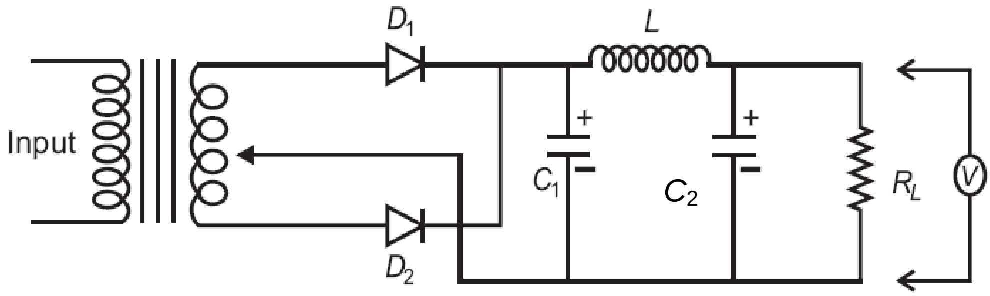


Fig. 10.10: **Circuit diagram of π-section filter.**

2. Measure V_{dc} and V_{ac} voltage across the load resistance R_L.
3. Repeat the experiment for different values of load resistances.
4. Record your observations in Observation Table 10.7.
5. Calculate the ripple factor for different loads.

Observation Table 10.7: π-filter

S.No.	Load resistance R_L (Ω)	Output (dc) Voltage V_{dc} (V)	Output (ac) Voltage V_{ac} (V)	Ripple factor $\gamma = \frac{V_{ac}}{V_{dc}}$

6. Connect the output of the load resistance R_L to the Y input of the cathode ray oscilloscope. Trace the output waveform for all values of R_L on tracing papers and paste them in your practical notebook.

SAQ 4 – L- and π-section filters

From your data find the difference between the waveforms of L- and π-section filters. Write your conclusion in your practical notebook.

Now briefly answer the questions given below.

a) What will happen if you give an unfiltered voltage to a radio set?

b) At heavy loads which kind of filter is preferable?